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ABSTRACT

Selected research studies that explore the assumption that college science students operate at a formal cognitive level are presented in this information digest. Studies are reviewed that relate to the areas of: (1) formal thought (examining the relationship between measured formal thought and that required to understand formal college physical science concepts and also the relationship between formal-operational thought and conceptual difficulties in genetics problem solving); (2) reasoning (discussing the effects of various methods and formats of administering a Piagetian reasoning problem and exploring the hypothesis that formal reasoning is required to balance even simple chemical equations); and (3) integrated process skills (reporting that process skills in the laboratory could significantly improve process skill achievement). (ML)

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RESEARCH IN COLLEGE SCIENCE TEACHING: COGNITIVE LEVELS AND REASONING

Teaching students to reason, to think critically, to solve problems in science has long been a concern at all levels. There is often an implicit assumption that college students operate at the formal level. The research reviewed for this Digest deals with this issue. The studies presented represent a sample of the research in this complex area. The sample is in no way exhaustive, nor can it be claimed to represent all areas of investigation. Rather, it is intended as an indication of the current state of the art with cognitive level or development of the learner as a common thread.

Formal Thought

The relationship between measured formal thought and that required to understand formal concepts in college level physical science was studied by Boram and Renner (1985). Using individual interview tasks, 49 students enrolled in a physics course for elementary teachers were evaluated for their abilities to use: (1) combinatorial logic, (2) separation and control of variables, (3) proportional reasoning, and (4) reciprocal implications. During one semester, the students were given experiences with 30 physics concepts; six of these concepts dealing with torque, electricity, optics, and heat were used in the research. Understanding these concepts required using one or more of the characteristics of formal thought. Analysis of the data led the investigators to conclude that a non-significant relationship exists between formal thought characteristics required to solve a problem and demonstrating the possession of those characteristics. When success on each of the interview tasks was correlated with success on each of the other interview tasks, all correlations were significant and moderately high, leading to the conclusion that success on a problem which requires formal thought depends on an overall formal thought structure.

Gipson and Abraham (1985) studied the relationships between formal-operational thought and conceptual difficulties in genetics problem solving. Seventy-one college general biology students were taught a unit in Mendelian genetics by the traditional lecture method emphasizing meiotic formation of gametes, dominance, segregation, and independent assortment. The Punnett square model was used for practice problems requiring the students to: (1) identify phenotype and genotype ratios that could be produced by parent organisms, (2) identify genotype and phenotype ratios from the resulting zygotic combinations, and (3) estimate the probabilities for gamete formations or zygote combinations. A unit test, followed eight weeks later by a content-validated posttest, was used to evaluate the students' problem solving skills. Both tests required the students to use proportional reasoning, combinatorial reasoning, and probablistic reasoning with problems similar to those involving practice with the Punnett square. Evaluation of the students' intellectual development was accomplished by means of three Piagetian tasks. No direct relationships were found between Piagetian and their corresponding occurrence in genetics problems. Significant differences were found for all three reasoning types among students of different levels of development. Formal-operational students had significantly more success in the three reasoning areas than did transitional students, and transitional students had significantly more success than did concrete-operational students.

Reasoning

Staver and Pascarella (1984) investigated the effects of various methods and formats of administering a Piagetian reasoning problem, the Mr. Short-Mr. Tall problem. The task was presented using four methods: (1) individual clinical interview, (2) group presentation of the task followed by paper-and-pencil problem with illustration, (3) group administration of paper-and-pencil instrument with illustration, and (4) group administration of paper-and-pencil instrument without illustration. Each method included four formats: (1) completion answer with essay justification, (2) completion answer with multiple choice justification, (3) multiple choice answer with essay justification, and (4) multiple choice answer with multiple choice justification. Three hundred seventy-six students who were enrolled in a freshman level biological science class were subjects in the study. A 4 × 4 factorial design was used with method and format of assessment as the main effects. The results showed that neither method nor format of assessment accounted for a significant amount of variance in student performance. The overall interaction was not significant.

Staver (1984) conducted a closely related study involving the mealworm problem, a Piagetian reasoning problem which requires students to control variables. The subjects were 253 students enrolled in a freshman level biological science class. The task was presented using the first three methods described in the preceding study with each of the three methods including the same four formats as described in the earlier study. The research design used was a 3 × 4 factorial with method and format of assessment as main effects. Regression analysis with the individual as the unit of analysis revealed that format but not method of assessment accounted for a significant amount of variance in student performance. The overall interaction was not significant. Staver concluded that these two studies clearly demonstrate that the method of administration for two separate Piagetian tasks of different reasoning patterns exerts no significant influence on subjects' scores. The format of assessment, however, can influence scores. The case for assessment of Piagetian reasoning patterns by group methods is, in the investigator's judgement, strengthened.

Niaz and Lawson (1985) conducted a study to test the hypothesis that formal reasoning is required to balance even simple one-step chemical equations, while formal reasoning and a sufficiently large mental capacity (for information processing) are required to balance more complex, many-step equations. Twenty-five students enrolled in one section of a nonmajor undergraduate science course were pretested

to determine their: (1) level of intellectual development, (2) mental capacity, and (3) ability to disembed relevant information from irrelevant background (i.e., their degree of field independence). It was predicted that when a sample of students that varied in developmental level (i.e., some concrete, some transitional, and some formal) and in mental capacity was taught how to balance equations in the traditional manner, then those who were concrete operational would fail to learn to balance equations because they had failed to internalize the basic hypothetico-deductive reasoning pattern required to assimilate the instruction and to subsequently balance the equations. On the other hand, those students who were formal operational would learn how to balance equations because they presumably had already acquired the necessary hypothetico-deductive reasoning pattern. The transitional students, it was predicted, would perform at a level intermediate to the concrete and formal students. Students were given instruction in using trial and error to balance chemical equations to ensure that all students understood that basic task-specific knowledge, that is, to control the experience variable as much as possible. Thus, any posttest differences would not be due to differences in task-specific knowledge but to developmental level or mental capacity. As part of the class final examination, a series of five unbalanced chemical equations was presented and the students asked to balance them. The reasoning required to balance the equations ranged in complexity from essentially a single step required in the simplest case to at least five or six steps needed in the most complex case. As predicted, the posttest revealed significant correlations between developmental level and equation balancing ability, for both simple and complex chemical equations. Also as predicted, mental capacity correlated significantly with complex equations but not with simple equations. Field dependence/independence played no significant role in performance.

Integrated Process Skills

Walkosz and Yeany (1984) compared the process skill achievement of college biology students (n = 107) completing traditional laboratory exercises with that of students (n = 127) completing the same exercises which had been modified to include instruction in such integrated process skills as identifying variables and stating hypotheses. The relationships among process skill achievement, cognitive development, overall course achievement, sex, and attitudes were also examined. The results indicated that emphasis on process skills in the laboratory could significantly improve process skill achievement. Students with lower levels of cognitive development had a lower level of process skill achievement, but there was no difference in gain in process skill achievement across levels of cognitive development. Females, on average, had a slightly lower level of cognitive development than did males, but there was no sex difference in process skill achievement overall. However, statistical interactions indicated that females at the lowest level of cognitive development scored higher than did males at the same level of development. In general, the study indicated that, along with gains in content achievement, process skill achievement can be improved in students at all levels of cognitive development through reasonable modifications of existing laboratory exercises.

Further Information

Readers interested in obtaining more information and additional research related to the topics reported in this Digest might want to conduct a search of the ERIC data base using the following terms:

College Science and *Cognitive Ability* or *Cognitive Development*
or *Cognitive Mapping* or *Cognitive Measurement*
or *Cognitive Processes* or *Cognitive Restructuring*
or *Cognitive Structures* or *Cognitive Styles*
or *Cognitive Theory*

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